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Procedia CIRP 46 (2016) 319 – 322

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7th HPC 2016 – CIRP Conference on High Performance Cutting

Experimental study on small-hole drilling characteristics of SiC_p/Al composites

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Abstract

In this paper, the small-hole drilling characteristics of high volume fraction SiC_p/Al composites using polycrystalline diamond (PCD) drills are studied experimentally. Wet pecking drilling operation is employed in the tests on account of the frequent fracture of small-diameter drills and serious tool wear. The thrust force and torque, drilled-hole surface quality, entry and exit hole edge defects and tool wear are measured, compared and analysed. The effect of drilling parameters on the thrust force, torque and surface roughness, the defect formation mechanism, tool wear pattern and mechanisms are discovered.

Peer-review under responsibility of the International Scientific Committee of 7th HPC 2016 in the person of the Conference Chair Prof. Matthias Putz
Keywords: Drilling; Composites; Diamond tool

1. Introduction

Silicon carbide particle reinforced aluminum matrix (SiC_p/Al) composites have been of great potential due to their superior physical and mechanical properties, such as high stiffness-to-weight ratio, high specific strength, high wear resistance, low sensitivity to temperature variations, and excellent corrosion resistance [1-3]. They have promising application prospect in many industrial fields like aerospace, marine, automotive and sport equipment [4,5]. However, SiC_p/Al composites are limited in the actual production applications by their poor machinability since the hard SiC particles embedded in the aluminum matrix lead to serious tool wear and undesired surface quality [6-8].

Carbide drill and PCD drills are mostly used for the drilling of SiC_p/Al composites, while HSS drills are unsuitable due to the rapid tool wear, poor hole quality and higher drilling forces induced. And the solid carbide drills also are characterized by some similar drilling characteristics even though superior to HSS drills. Only PCD drills are most desirable for machining SiC_p/Al composites especially with high volume fraction and large particles because of their highest tool wear resistance [1,9].

Up to now, most research works concentrated on the drilling process of SiC_p/Al composites with volume fraction less than 30% and drill diameter larger than 4 mm. Huang et al. investigated drilling performance of high volume fraction composites 56% SiC_p/Al with PCD drills of 4.6 mm diameter [1]. Very little research work is performed on drilling of high volume fraction SiC_p/Al composites with small-diameter drills, although it has become a much needed technology after the successful breakthrough of narrow slot milling technology in the present industry such as the electronic packaging field.

In this study, experiments of drilling 3mm-diameter holes on 65% SiC_p/Al composite plate with PCD brazed drills are carried out for the investigation of the drilling mechanism, including thrust force and torque, surface quality, entry and exit hole edge defects and tool wear.

2. Experimental procedure

2.1. Workpiece

Materials used for the drilling tests are 65% volume fraction SiC_p/Al (SiC_p/Al6063/65p) composites fabricated by the vacuum infiltration method. The microstructure is shown

Peer-review under responsibility of the International Scientific Committee of 7th HPC 2016 in the person of the Conference Chair Prof. Matthias Putz
doi:10.1016/j.procir.2016.03.124

in Fig. 1, in which the dark polyhedral SiC particles with many sharp corners are homogeneously distributed in the light aluminum matrix, and the average size of the SiC particles is 10 μm.

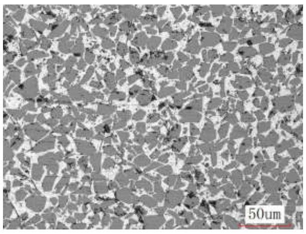


Fig. 1 Microstructure of SiCp/Al6063/65p composites.

2.2. Equipment setup and procedure

The tiny chips always clog at the bottom of the holes and are difficult to get removed without the injection of coolant. And this will result in high temperature, rapid tool wear, high thrust force and frequent fracture of the drills. Therefore, wet pec drilling operation is utilized in the drilling experiments for the in-time cooling of the drill bits and chip removal.

The drilling tests are conducted on an ODG KT-600 CNC machine tool with external cooling system, as shown in Fig. 2. The 3 mm-diameter carbide drills with two brazed PCD tips, a point angle of 120°, relief angle 10°, rake angle 0° and helix angle 30° are used for the experiments. Peck drilling is performed on a 2mm thick SiC_p/Al plate with the combined drilling parameters of a rotation speed of 1500, 2000 or 2500rpm, a feed velocity of 50, 75 or 100mm/min, and a drilling depth of each step of 0.075mm.

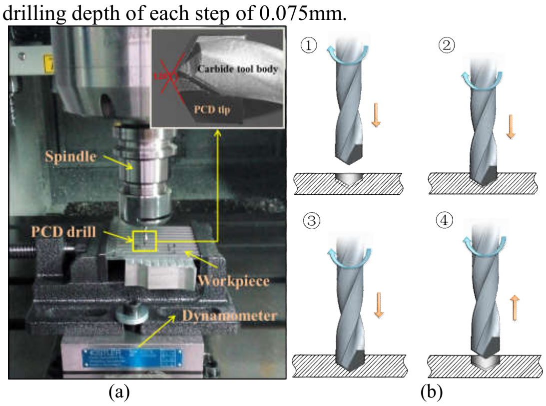


Fig. 2 Peck drilling experiment. (a) experiment setup; (b) 4 parts of one step.

3. Result and discussion

3.1. Thrust force and torque

In the drilling experiments, the drilling forces are recorded using a Kistler 9257B dynamometer. Fig. 3 shows the thrust force variation with the drilling in and out per step at a rotational speed of 2000 rpm and feed velocity of 100 mm/min. As the PCD drill inserts construct a point angle of 120°, it can be calculated that the vertical height of main cutting edge is 0.866mm. It takes 38.2 drilling steps to drill through the 2mm-thick workpiece completely with a drilling depth of 0.075 mm per step, while in Fig. 3 the non-zero force signal covers 40 steps drilling process due to the elastic deformation of the workpiece in drilling. The average peak values of thrust force and torque in the stable feed drilling stage are taken to analyze the variation of thrust force and torque with respect to the rotational speed and feed velocity, as shown in Fig. 4. And it is found that both thrust force and torques are highly dependent on the feed rate and the parameter combination of high rotation speed and low feed velocity is preferred.

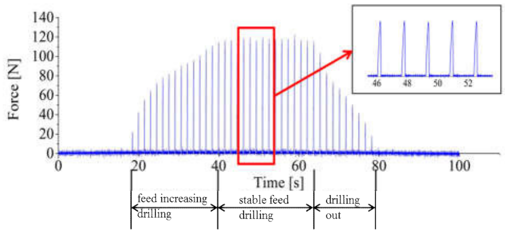


Fig. 3 Recorded thrust force at a rotational speed of 2000 rpm and feed velocity of 100 mm/min.

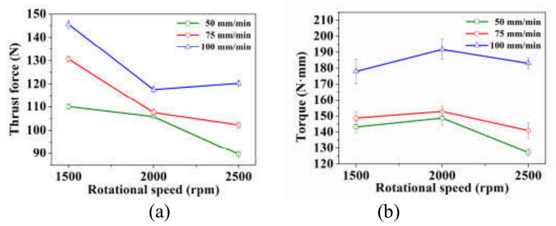


Fig. 4 Variation of experiment data in drilling SiC_p/Al6063/65p composites. (a) thrust force; (b) torque.

3.2. Surface quality of drilled hole

In order to measure the surface roughness, the work is cut into two approximately equal pieces along the hole axis. Surface roughness (Ra) is measured along the hole axis at four different positions of hole inner surface with approximately 90° intervals around the circumference by using a VK-X200 3D Laser Scanning Microscope. At last an average value is calculated and used in Fig. 5.

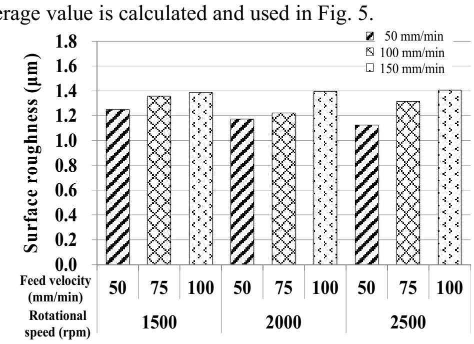
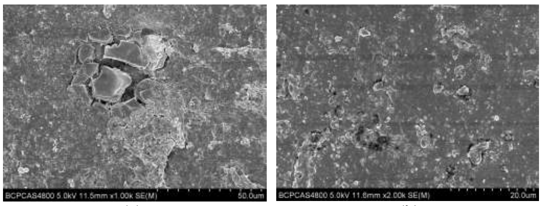


Fig. 5 Surface roughness Ra with variation in rotational speed and feed velocity.

Fig. 5 shows that compared to the effect of feed velocity on drilled hole surface roughness, rotational speed has insignificant influence. The lowest surface roughness value of Ra 1.1μm is produced at the parameter combination of the lowest feed velocity and highest rotational speed. It is analyzed that the SiC particles were pulled out, crushed and trapped between the tool and the drilled surface by the most strong burnishing and honing effect [10, 11]. The micrographs of the hole surface in Fig. 6 exhibit some amount of micro-defects in existence. In details, it is witnessed that the SiC particle with a feature size larger than 20μm is clearly fractured under the squeezing effect of the tool edges and tool faces of the PCD drill in Fig. 6(a), and a considerable number of pits appears on the surfaces in Fig. 6(b), which might be due to the evulsion of sharp corners of SiC particles from the matrix.



(a) (b)

Fig.6 Microdefects of the machined surfaces. (a) fracture of SiC_p and micro cracks; (b) pits formed by pulling out of SiC_p.

3.3. Drilled edge defects

Fig. 7 shows the entry and exit edge defects observed along the hole-axis direction. It can be seen that the entry edge defects are predominantly caused by spalling and fracture of the SiC particles embedded within the area of the entry edge. When the main cutting edge penetrates into the surface of workpiece, the SiC particles, around the outer cutting edge, are peeled off from the entry edge. Besides, some large SiC particle held by aluminium matrix are fractured under the cutting effect of the lip edge and some weakly bonded ones are pulled out under the shoving and squeezing effect.

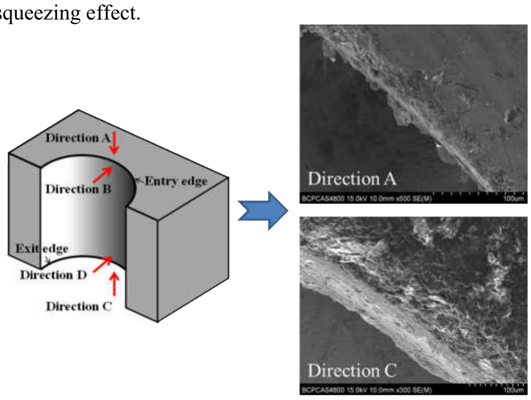
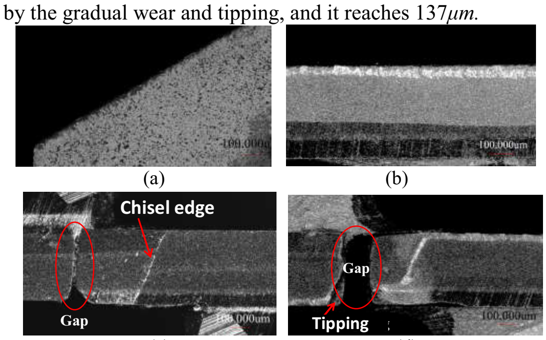


Fig. 7 SEM images of edge defects at the rotational speed of 1500 rpm and feed velocity of 75 mm/min.

The exit edge defects are mostly attributed to extensive spalling between SiC particles and Al matrix and a large number of notches continuously distribute along the edge are witnessed. The inherent defects and voids existing in the composites become initial crack origins and easily propagate due to the low shear strength of the hard-brittle material while the drill cutting through the remaining thin layer material at the bottom of the hole. At last, the SiC particles and Al matrix are pushed out as a whole piece.

3.4. Tool wear and wear mechanism

Fig. 8 shows the worn PCD drill after drilling 10 holes at a rotation speed of 2000r/min and feed velocity of 75mm/min. The discontinuous and tiny chips of the high volume fraction SiCp/Al composites produce a very limited contact length with high stress and high temperature at the rake face during drilling process, and the frequently intense impact of hard SiC particles results in a large number of micro-chippings of the lip edge, as shown in Fig. 8(a) & (b) and a maximum flank wear of 63μm is found at the outermost part of the lip edge. In Fig. 8(d), the chisel edge becomes worn [1, 12] under the high thrust force produced by the extrusion action of large negative rake angle, and the serious wear action makes the two originally sharp corners rounded. In addition, it is witnessed that the gap between the two PCD tips becomes much widen by the gradual wear and tipping, and it reaches 137μm.



(a) (b) (c) (d)

Fig. 8 Worn PCD drill. (a) rake face of lip edge; (b) flank face of lip edge; (c) chisel edge before drilling (d) chisel edge after drilling

4. Conclusion

(1) In peck drilling of SiC_p/Al composites with high volume fraction, feed velocity has more significant effect on the thrust force and torque than the rotational speed.
(2) The fact that the decreasing of feed velocity is helpful for the improvement of machined surface quality is explained by the enhanced burnishing and honing effect of SiC particles taking place between the tool and the drilled surface. Besides, the drilled hole surface roughness decreases with the increase of feed velocity. However, the rotational speed acted no influence on the surface roughness.
(3) The entry edge defect was the result from spalling and fracture of SiC particles. The exit edge defect is formed by extensive spalling actions. And the exit edge defects were significantly serious than that of entry edge due to the high force exerted on the uncut rest workpiece.

(4) The flank wear and chisel edge wear occurred on the PCD drill is more likely broken down due to too widened gap between two PCD tips caused by serious tipping, and the wear mechanisms mainly include abrasive wear and micro-tipping.

Acknowledgement

This work is supported by the National Natural Science Foundation of China (Item No.: 51575051).

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